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Environmental Research 100 (2006) 295–318

Environmental Research

www.elsevier.com/locate/envres

Maternal and umbilical cord blood levels of mercury, lead, cadmium, and essential trace elements in Arctic Canada ☆

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Received 1 January 2005; received in revised form 18 May 2005; accepted 26 May 2005
Available online 3 August 2005

Abstract

Maternal and umbilical cord blood levels of mercury (Hg), lead (Pb), cadmium (Cd), and the trace elements copper (Cu), zinc (Zn), and selenium (Se) are reported for Inuit, Dene/Métis, Caucasian, and Other nonaboriginal participants from Arctic Canada. This is the first human tissue monitoring program covering the entire Northwest Territories and Nunavut for multiple contaminants and establishes a baseline upon which future comparisons can be made. Results for chlorinated organic pesticides and PCBs for these participants have been reported elsewhere. Between May 1994 and June 1999, 523 women volunteered to participate by giving their written informed consent, resulting in the collection of 386 maternal blood samples, 407 cord samples, and 351 cord:maternal paired samples. Geometric mean (GM) maternal total mercury (THg) concentrations ranged from 0.87 μg/L (SD = 1.95) in the Caucasian group of participants ($n = 134$) to 3.51 μg/L (SD = 8.30) in the Inuit group ($n = 146$). The GM of the Inuit group was 2.6-fold higher than that of the Dene/Métis group (1.35 μg/L, SD = 1.60, $n = 92$) and significantly higher than those of all other groups ($P<0.0001$). Of Inuit women participants, 3% ($n = 4$) were within Health Canada's level of concern range (20–99 μg/L) for methylmercury (MeHg) exposure. Of Inuit and Dene/Métis cord samples, 56% ($n = 95$) and 5% ($n = 4$), respectively, exceeded 5.8 μg/L MeHg, the revised US Environmental Protection Agency lower benchmark dose. GM maternal Pb was significantly higher in Dene/Métis (30.9 μg/L or 3.1 μg/dL; SD = 29.1 μg/L) and Inuit (31.6 μg/L, SD = 38.3) participants compared with the Caucasian group (20.6 μg/L, SD = 17.9) ($P<0.0001$). Half of all participants were smokers. GM blood Cd in moderate smokers (1–8 cigarettes/day) and in heavy smokers (>8 cigarettes/day) was 7.4-fold higher and 12.5-fold higher, respectively, than in nonsmokers. The high percentage of smokers among Inuit (77%) and Dene/Métis (48%) participants highlights the need for ongoing public health action directed at tobacco prevention, reduction, and cessation for women of reproductive age. Pb and THg were detected in more than 95% of all cord blood samples, with GMs of 21 μg/L and 2.7 μg/L, respectively, and Cd was detected in 26% of all cord samples, with a GM of 0.08 μg/L. Cord:maternal ratios from paired samples ranged from 0.44 to 4.5 for THg, from 0.5 to 10.3 for MeHg, and 0.1 to 9.0 for Pb. On average, levels of THg, MeHg, and Zn were significantly higher in cord blood than in maternal blood ($P<0.0001$), whereas maternal Cd, Pb, Se, and Cu levels were significantly higher than those in cord blood ($P<0.0001$). There

☆ Funding for this work was provided by Canada's Northern Contaminants Program (Department of Indian Affairs and Northern Development) from 1991 to 2000. The Government of the Northwest Territories and Health Canada supported the production of this paper, thereby fulfilling a commitment made to participants.The protocol received ethical approval from the agency or agencies appropriate to each region and all participants provided written informed consent.

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doi:10.1016/j.envres.2005.05.006

was no significant relationship between methylmercury and selenium for the range of MeHg exposures in this study. Ongoing monitoring of populations at risk and traditional food species, as well as continued international efforts to reduce anthropogenic sources of mercury, are recommended.

Keywords: Mercury; Trace elements; Tobacco; Arctic indigenous women; Maternal/cord blood; Cadmium; Lead

1. Introduction

The presence of multiple contaminants is of concern in the circumpolar north in all ecosystem compartments and has received considerable attention, particularly over the past two decades (AMAP, 1998, 2003).

In Canada, the identification of elevated levels of polychlorinated biphenyls (PCBs) in the breast milk of Inuit women in Northern Quebec (Dewailly et al., 1989) catalyzed national attention and action to answer the many questions raised by this finding. A subsequent synthesis of current knowledge indicated that the Arctic marine ecosystem was contaminated with multiple organochlorines and metals, including species consumed by Inuit (Muir et al., 1992), and that there was widespread contamination of inland Arctic fisheries by organochlorine and metal contaminants, including species consumed by Dene/Métis and Inuit (Lockhart et al., 1992). Anthropogenic contaminants were entering the North via atmospheric and oceanic long-range transport mechanisms (Barrie et al., 1992). Of particular concern was that elevated levels of PCBs, toxaphene, and mercury were identified in some Inuit residents in one community in Nunavut (Kinloch et al., 1992). The Canadian government responded by establishing the Arctic Environmental Strategy's Northern Contaminants Program (NCP) in 1991. The Arctic Monitoring and Assessment Programme (AMAP), a circumpolar initiative established to assess the state of multiple compartments in the Arctic ecosystem, including human health, was also initiated at this time (AMAP, 1998).

The presence of methylmercury in aboriginal peoples in northern and southern Canada had previously been investigated. Health Canada's Methylmercury Monitoring Program highlighted elevated levels of mercury in Dene and Inuit in the North, as well as in First Nations elsewhere in Canada (Wheatley et al., 1979; Wheatley and Paradis, 1995). These results indicated that during the time of sampling (1972–1989), 20% of Dene and 57% of Inuit men and women sampled had blood methylmercury levels that exceeded the 20 μg/L guideline for "an increasing risk of health effects" related to methylmercury exposure (Wheatley and Paradis, 1995). Elevated levels of mercury were also reported in some Greenlandic Inuit. These elevated levels were linked to seal consumption, with those consuming more than six meals/week having a mean blood mercury value of 62.5 μg/L, while those eating one meal of seal or less/week having a mean mercury value of 22.2 μg/L (Hansen et al., 1983).

In response to concerns about the presence of environmental contaminants in the Northwest Territories (NWT) and the importance of traditional foods to indigenous Northerners, the Government of the NWT Department of Health, in collaboration with the NCP and others, initiated discussions in 1991 to develop technical and communications protocols for establishing an exposure baseline for mothers and newborns in the NWT. Mothers and their newborns were the target populations because of evidence that the fetus was particularly vulnerable to exposure to various contaminants, including possible neurodevelopment deficits resulting from in utero PCB exposure (Jacobson et al., 1992) and neurological and developmental abnormalities related to prenatal mercury exposure (WHO, 1990). It was clear from the outset that there were multiple perspectives that needed to be considered in the development of an approach that would not raise undue concerns in participants and communities. Extensive consultations with regional health boards, community representatives, regional and national aboriginal organizations, universities, and territorial and federal agencies took place over a period of more than 2 years. As a result of these consultations, which included community, regional and territorial workshops, conference calls, face-to-face meetings, and community visits, a "grassroots" participatory action research approach was developed in, by, and with communities and others to include meaningful community involvement in all stages of the program (Walker et al., 2001).

The objectives of this territorial baseline monitoring program were (1) to assess exposure to specific metal and organochlorine contaminants in NWT mothers and their newborns; (2) to develop a process for the meaningful participation of community representatives and health workers in all phases of the project; (3) to investigate the relationship between contaminant levels in maternal blood and cord blood; and (4) to contribute to national and international databases to assist efforts to reduce contaminant levels in the North.

Contaminants measured as part of the overall monitoring program included organochlorines (PCBs and 14 chlorinated pesticides), mercury, cadmium, lead, and the essential trace elements copper, selenium, and zinc. The maternal and umbilical cord blood organochlorine results have been reported (Butler Walker et al., 2003). The present paper reports mercury, cadmium, lead, copper, zinc, and selenium levels measured in maternal and umbilical cord blood from the same nonrandom sample of participants between 1994 and 1999 as well as preliminary results about the relationship between maternal and fetal exposure at the time of sampling. Subsets of this data have been included in the Canadian Arctic Contaminants Assessment Reports (Jensen et al., 1997; Van Oostdam et al., 2003), the AMAP Reports (1998, 2003), and Van Oostdam et al. (1999). These data are included here to provide a comprehensive summary of data collected across the NWT and Nunavut. The AMAP human health blood monitoring protocol included sampling maternal blood and cord blood for mercury, cadmium, lead, a suite of organochlorine pesticides, PCBs, and the essential trace elements zinc, copper, and selenium (AMAP, 1998). The protocol developed for the NWT and Nunavut exposure assessment included these contaminants and specific essential trace elements to constitute part of Canada's contribution to the AMAP initiative.

Program implementation occurred in each of the five geographically defined health regions (Fig. 1) and took place prior to the division of the NWT with the creation of Nunavut in 1999. These five health regions implemented the monitoring program as it became feasible for their respective boards. The ethnic composition of the health regions varied, with Inuit predominantly residing in the Baffin, Kitikmeot, and Kivalliq Regions; Dene/Métis, Caucasians, and Inuit (Inuvialuit, which are Inuit from the Mackenzie Delta Region) in the Inuvik Region; and Dene/Métis and Caucasians in the Mackenzie Region.

2. Methods

Similar methods for recruitment, informed consent, sampling, analysis, and results communication were used in each of the five health regions as part of the territorywide program, although some regions collected additional information. These methods are described in

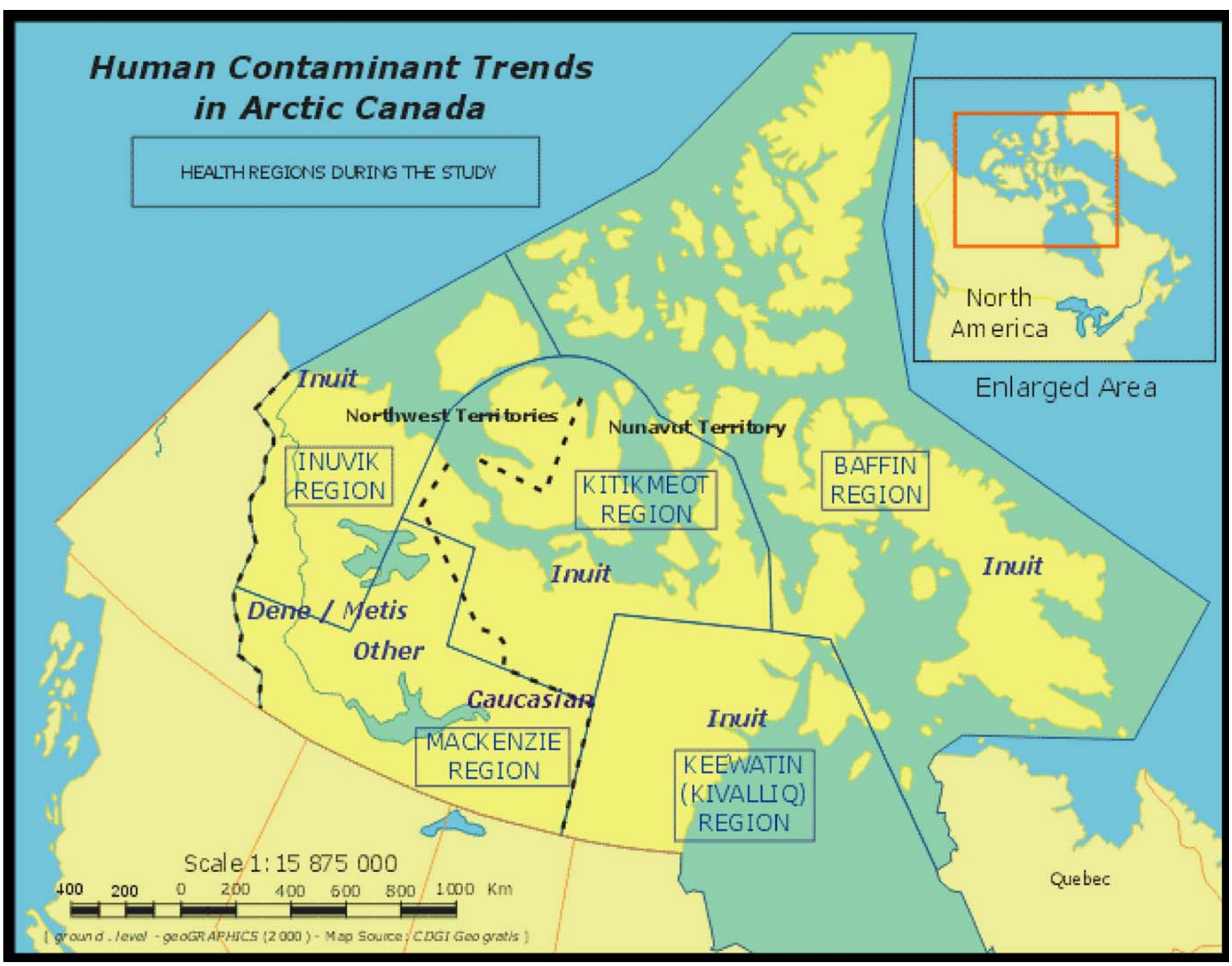

Fig. 1. Health regions in effect during the study (prior to the creation of Nunavut, with the NWT/Nunavut boundary post-1999 included).

the following regional reports and are summarized in a Final Technical Report (Walker et al., 2001): Mackenzie Regional Health Service and Kitikmeot Health and Social Services Board (Seddon et al., 1998); Baffin Regional Health and Social Services Board (Moss, 1997); Keewatin Regional Health and Social Services Board (1997); and the Inuvik Regional Health and Social Services Board (Tofflemire, 2000).

2.1. Participant recruitment and informed consent

Prenatal clients were introduced to the program and invited to participate by a health worker during their routine prenatal care. Potential participants received plain-language information about the program, both verbally and in writing, in English or Inuktitut. Women confirmed their participation by signing a consent form. The consent form stated that participation was voluntary, their confidentiality was assured, their individual results for contaminants with guidelines would be available to them before they were reported elsewhere, they could withdraw from the program at any time, and the overall results would contribute toward national and international efforts to reduce contaminants entering the North. Participants had the option to donate a cord blood sample, a maternal blood sample, or both.

2.2. Sampling

A dietary and lifestyle questionnaire was administered in either English or Inuktitut. The questionnaires differed somewhat between regions, but all acquired demographic information, tobacco use, and a brief description of traditional foods consumed. Traditional food consumption was not quantified systematically and quantitatively due to logistical and resource constraints. General consumption information was collected to assist with individual results interpretation.

Maternal blood samples were drawn between 36 weeks gestation and before release from the hospital following delivery. A 7-mL lavender-top vacutainer was used to draw 7 mL of blood from the participant for cadmium (Cd), mercury (Hg), and lead (Pb) analyses. A 7-mL blue-top vacutainer was used to collect blood for the copper (Cu), zinc (Zn), and selenium (Se) analysis. Umbilical cord blood was sampled at the time of delivery; 7 mL of umbilical cord blood was drawn into a lavender-top vacutainer for heavy metals analysis and a blue-top vacutainer for trace element analysis. Each vacutainer contained an EDTA anticoagulant. The lavender-top vacutainers were each transferred directly into 7-mL polyethylene tubes for whole blood analysis of Cd, Hg, and Pb. The blue-top vacutainer tubes were centrifuged for 10 min to separate plasma. Using a pipette, 2 mL of plasma was placed in 7-mL polyethylene tubes for the trace metals analysis of the cord and maternal blood. The tubes were frozen for storage and shipment to the Laboratoire de Toxicologie, Institut national de santé publique du Québec (formerly part of the Centre hospitalier Universitaire de Québec, Laboratoire de Toxicologie, Laval University).

2.3. Samples analysis

Blood mercury concentrations (total and inorganic) were determined using 500 μL of blood digested with an equal volume of nitric acid using cold-vapor atomic-absorption spectrometry. The limit of detection was 0.2 μg/L. Methods for detecting total mercury and organic mercury are detailed in Ebbestadt et al. (1975). Cadmium concentrations were detected using graphite-furnace atomic-absorption spectrometry, with 100 μL of blood added and mixed to 500 μL of diluent (0.4% Triton X-100, 0.06% magnesium nitrate, and 1% ammonium phosphate). The detection limit was 0.2 μg/L (Stoeppler et al., 1980). Blood lead concentrations were determined using graphite-furnace atomic-absorption spectrometry, with 100 μL of blood in 1 mL of diluent (0.5% Triton X-100, 0.2% nitric acid, and 0.1% ammonium phosphate). The method detection limit was 10 μg/L (Parsons and Slavin, 1993). Copper, zinc, and selenium were determined in maternal and umbilical cord plasma samples. Copper concentrations were determined using graphite-furnace atomic-absorption spectrometry, with 100 μL of plasma added and mixed to 5 mL of a diluent solution (0.4% Triton X-100, 1% ammonium phosphate, and 0.06% magnesium nitrate). The detection limit was 64 μg/L (Perkin-Elmer, 1991). Zinc concentrations were determined using flame atomic-absorption spectrometry, with 500 μL of plasma diluted in 2.5 mL of 0.5% Triton X-100. The detection limit was 200 μg/L (Perkin-Elmer, 1994). Selenium concentrations were determined using graphite-furnace atomic-absorption spectrometry, with 100 μL of plasma added and mixed to 200 μL of 0.05% Triton X-100. The detection limit was 15 μg/L (Neve et al., 1987). Routine checks of accuracy and precision were accomplished using reference materials from the Laboratoire de Toxicologie, Institut national de santé publique du Québec interlaboratory comparison program. For lead, interlaboratory comparison programs included the Blood Lead Laboratory Reference System, the Centers for Disease Control, Atlanta, GA, USA, the State of New York Department of Health, USA, and Ontario's Ministry of Health, Canada. For Hg, Cd, Cu, Se, and Zn, the Laboratoire de Toxicologie, Institut national de santé publique du Québec interlaboratory proficiency program was used.

2.4. Statistical analysis

Statistical analysis were conducted using the statistical software programs SAS (SAS Institute, 1996) and SPlus (Insightful Corp., 2001). Descriptive statistics were calculated for metals and essential trace elements, including minimum, median, and maximum values, arithmetic mean and standard deviation, geometric mean (GM) and standard deviation, and percentage detected. All maternal and cord data were log-normally distributed, with the exception of maternal Cu and Se; both arithmetic and GMs were calculated and are presented to facilitate comparisons with a wider range of studies in the literature. Undetected samples were assigned a value of one half (1/2) the detection limit.

Comparisons between ethnic and regional groups were made using an ANOVA model. A model was fit with the covariate (ethnic or regional group) as the only main effect. An F-test was conducted to test for overall differences between the groups. If the F-test was significant ($P<0.05$), Tukey's t-test was conducted to test for multiple pairwise differences between the groups (Tukey, 1953). A P value of less than 0.05 when testing two groups indicated a significant difference between the groups. Statistical tests were performed using GMs.

For the analysis of cigarette use and maternal cadmium levels, participants were categorized into three approximately even groups according to their reported cigarette use: nonsmokers, moderate smokers ($\leqslant 8$ cigarettes per day), or heavy smokers (>8 cigarettes per day). Based on survey responses, too few women used other forms of tobacco (cigars/cigarillos, chewing tobacco, pipe tobacco) to assess the effect of this lifestyle choice on maternal cadmium levels.

A calculation of traditional food consumption was performed to provide an indication of traditional food use. Regional dietary survey instruments differed somewhat, and with the exception of the Inuvik Region, were not designed to quantitatively evaluate the consumption of various species in the NWT and Nunavut. Accordingly, additional information was included in the data analysis to facilitate these calculations based on data from dietary surveys conducted in the same regions by the Centre for Indigenous Peoples' Nutrition and the Environment (CINE), McGill University, Montreal, Quebec, Canada. The results of the surveys were standardized to allow for comparisons between reported frequencies of consumption. Daily serving sizes for each of the six traditional food categories were assigned based on work conducted in the NWT for Dene and Métis (Receveur et al., 1996) and preliminary work in Nunavut for Inuit (O. Receveur, pers. comm.). The categories of traditional foods included marine mammal meat, marine mammal fat/muktak, marine mammal organs, terrestrial mammal meat, terrestrial mammal organs, fish and clams, and birds. Harvest months were the number of months per year that a species was "readily available," which was how the food-use questions were asked in most of the surveys. Harvest months were quantified as months of availability in each of 30 communities and were based on previous work conducted by CINE. This work included consultations with two community representatives from each community in Nunavut in 1998 for their project "Assessment of Dietary Benefit:Risk in Inuit Communities" and also their work in 1993 for communities in the Mackenzie Region for their project "Variance in Food Use in Dene/Métis Communities" (Receveur et al., 1996; Berti et al., 1998). Thus, the annual consumption of traditional food was calculated by multiplying the daily consumption (calculated as the frequency of consumption per week/7) by the assigned daily serving size by the number of days consumed (calculated as the number of harvest months/12 in days).

For the aggregate category of "all traditional foods," and with 115 g/day as the median value, consumers were categorized as nonconsumers, moderate consumers (<115 g/day), and high consumers ($\geqslant 115$ g/day) to establish group sizes that were approximately even. The aggregate category all traditional foods was a single cumulative measure representing the frequency of consumption for all species and all tissue types as described above. It was developed to provide a general indication of traditional food consumption that included multiple species. This was done to facilitate comparisons between the estimates for overall traditional food consumption in relation to tobacco use and maternal cadmium exposure.

3. Results

Regional results were reported by the respective health agencies: Mackenzie Regional Health Service and Kitikmeot Health and Social Services Board (Seddon et al., 1998); Baffin Regional Health and Social Services Board (Moss, 1997); Keewatin Regional Health and Social Services Board (1997); and the Inuvik Regional Health and Social Services Board (Tofflemire, 2000). These regional results were merged to produce a territorial dataset and subsequently analyzed on a territorial basis as summarized in Walker et al. (2001).

3.1. Recruitment

Altogether, a total of 523 women volunteered to participate in the overall monitoring program between May 1994 and June 1999. Recruitment rates varied between regions: the Inuvik Region reported the highest rate, with 76% of the available prenatal clients participating, followed by the Kitikmeot with 50%, the Mackenzie at 43%, the Baffin at 33%, and the

Kivalliq at 30%. Recruitment occurred for 12 months in the Mackenzie (May 1994–1995), Baffin (January–December 1996), Kitikmeot (May 1994–June 1995), and Inuvik Regions (June 1998–1999) and for six months in the Kivalliq Region (July 1996–January 1997). The overall participation rate was 49%, and the participation rate of those who donated a maternal and/or a cord blood sample was 45%.

3.2. Demographics

The ethnic composition of participants who donated a maternal sample and a cord sample included Inuit, Dene, Métis, Caucasians, and Other nonaboriginals (Chinese, East Indian, Filipino, and multiple ethnicity). They ranged in age from 15 to 45 years old. There were significant differences in mean age between ethnic groups ($P<0.0001$). Pairwise tests showed that Caucasians were significantly older (31.5 ± 5.2 years) than Inuit (25.2 ± 5.5 years), while Dene/Métis (26.9 ± 5.9 years) and Inuit (25 ± 5.5) were not significantly different (Table 1). Among Inuit participants, those from the Kitikmeot Region were significantly older (26.4 years) than participants from the Baffin (23.6 years) and Inuvik Regions (23 years), which were not significantly different from Kivalliq participants (24.9 years) ($P<0.0026$). Data were not age adjusted due to significant contaminant differences and age structures among the various ethnic groups.

Fifty-three percent of all participants regularly smoked cigarettes. These included 77% of the Inuit, 48% of the Dene/Métis, 22% of the Caucasian, and 6% of the Other nonaboriginal participants. In general, Inuit, Dene, and Métis participants reported living in the region in which they were residing for at least the previous 5 years, whereas nearly one-third of nonaboriginal participants had lived outside their present region in the past 5 years. Eighty-five percent of participants reported no occupational exposure to organochlorine or metal contaminants. Participants that reported occupational exposures included gas/mining, painting, cleaning, health care, and other jobs.

Ninety-three percent of all participants reported consuming at least some traditional foods, with species and amounts reported as consumed varying between ethnic groups and regions as described in the regional reports noted at the beginning of Results. Caribou meat was the traditional food most frequently consumed by most Nunavut Inuit participants, followed by fish and marine mammals (beluga and seal, respectively) for Kivalliq and Kitikmeot participants, and ringed seal and fish for Baffin participants. The next most commonly consumed species among Kivalliq, Kitikmeot, and Baffin participants were seal and waterfowl (duck, goose, swan), beluga/narwhal and waterfowl, and narwhal and beluga, respectively.

In the Inuvik Region, 40% of all participants consumed caribou at least once a week, and 10% consumed it more than four times per week. Inuvialuit participants consumed sea-run arctic char, herring, beluga fat, and meat more than other participants from this region. Dene/Métis participants from the Inuvik Region consumed more moose, hare, whitefish, blueberries, and sea ducks than other groups from this region. Dene/Métis participants living in the Mackenzie Region reported commonly consuming caribou, moose, fish, and waterfowl (duck, goose, and swan), with rabbit, grouse/ptarmigan, and bison consumed the next-most frequently.

3.3. Maternal Hg, Cd, Pb, Cu, Se, Zn

Results from maternal blood analysis are reported according to participants' self-described ethnicity, which included Caucasian, Dene/Métis, Other nonaboriginal, and Inuit and are also presented for all participants combined. The Inuit data are presented in more detail and categorized according to the geographically defined health regions at the time of sampling—the Baffin, Kivalliq (then called Keewatin), Kitikmeot, and Inuvik Regions. These data are presented in more detail to explore geographical similarities and differences in Inuit participants across the North. The Dene and Métis and Caucasian participants were located almost exclusively in the western NWT (Mackenzie and Inuvik Regions), and their data were combined, as there were no significant differences between these groups.

Table 1
Demographic characteristics of participants who donated a maternal blood sample and a cord blood sample

Ethnic origin	Number of mothers	Mean age	Age (SD)	Minimum age	Maximum age	Significant difference[a]
Caucasian	124	31.5	5.2	19	45	a
Dene/Métis	83	26.9	5.9	18	45	b,c
Inuit	132	25.0	5.5	15	39	c
Other	13	30.6	5.2	21	38	a,b
Total	352	27.9	6.1	15	45	

[a] *F*-test *P* value <0.0001 for overall significant difference; a, b, c comparisons are Tukey's *t*-test, where groups which do not have a common letter are significantly different ($P<0.05$).

Table 2
Summary of maternal metals (in blood) and trace elements (in plasma); results for all maternal participants (μg/L)

Contaminant	N	Minimum	Maximum	Arithmetic mean	Geometric mean	Detection limit	% detected
Blood							
Inorganic mercury	385	ND	4.6	0.78	0.53	0.2	88.1
Methylmercury[a]	385	0.00[b]	29.3	2.20	1.30	NA	NA
Total mercury	385	ND	33.9	2.96	1.66	0.2	94.6
Lead	385	2.07	178	33.6	26.7	10.0	95.8
Cadmium	385	ND	8.5	1.72	0.76	0.2	84.7
Plasma							
Copper	383	172	3598	2160	2097	65	100
Selenium	381	67	184	121	120	15	100
Zinc	380	180	5207	581	555	200	100

ND, not detected; NA, not applicable.
[a]Methylmercury was calculated as the difference between total Hg and inorganic Hg.
[b]Methylmercury was given a value of zero whenever inorganic Hg equaled or exceeded total Hg.

The data are reported by ethnicity because of differences in traditional food species consumed and are not intended to imply a predisposition to an exposure range based on ethnic origin.

Maternal results for all participants for mercury, lead, and cadmium in whole blood and selenium, copper, and zinc in plasma are summarized in Table 2. These results show that for all ethnic groups combined, the GM levels for Hg, Cd, and Pb were 1.7, 0.8, and 27 μg/L, respectively, across the NWT and Nunavut.

The number of participants in each of the ethnic groups that donated a maternal sample ranged from 13 in the Other nonaboriginal group to 146 in the Inuit group, with 92 Dene/Métis and 134 Caucasian participants contributing altogether.

Maternal results are reported by ethnicity for participants self-identified as Caucasians, Dene/Métis, Other nonaboriginal, or Inuit. These results are summarized in Table 3 and include arithmetic and GMs; all data were log-normally distributed, except maternal Cu and Se. In Table 3, below the combined Inuit results ($n = 146$), results are reported for Inuit participants according to the health region in which they lived, as described in Fig. 1. There were four Inuit participants who were living in the Mackenzie Region at the time of sampling in that region. Data from these four participants were included in the combined Inuit results, but were not attributed to a specific region in the preliminary spatial description by region, which is why the sum of participants from the regions is four less than the total for all Inuit in Table 3.

3.4. Mercury

Results for inorganic mercury (IHg) and both total mercury and methylmercury (MeHg) are reported. Methylmercury was calculated as the difference between total mercury and inorganic mercury. This assumes that the majority of the organic mercury is MeHg, and while the species were not characterized, the term methylmercury is acceptably used to refer to the difference between total and inorganic mercury (WHO, 1990). THg was detected in 88% of Caucasians, 98% of Dene/Métis and Inuit participants, and 100% of the Other nonaboriginal participants (Table 3). GM THg maternal concentrations ranged from 0.87 μg/L (SD = 1.95) in the Caucasian group to 3.51 μg/L (SD = 8.30) in the Inuit group (Table 3). The GM of the Inuit group was 2.6-fold higher than that of the Dene/Métis group (1.35 μg/L, SD = 1.60) and significantly higher than those of all other groups ($P<0.0001$). Among Inuit participants, those from the Baffin Region had a significantly higher mean THg concentration than those from the Inuvik and Kitikmeot Regions ($P<0.0001$) and a mean concentration 1.8-fold higher than the participants from the Kivalliq Region, the next largest mean (Table 3). As expected, the pattern of MeHg exposure was similar to that of THg, with a significantly higher GM concentration for Inuit participants (2.87 μg/L, SD = 6.91) relative to other participant groups ($P<0.0001$). The GM MeHg for Inuit participants from the Baffin Region (5.97 μg/L, SD = 9.68) was significantly higher than GMs for the other regions with Inuit participants ($P<0.0001$) (Table 3).

Health Canada's guidelines for MeHg recommend a "level of concern" or "increasing risk" for blood levels between 20 and 100 μg/L and a "level of action" or "at risk" for blood levels greater than 100 μg/L (Health Canada, 1999; Van Oostdam et al., 1999). With a maximum individual maternal MeHg level of 29.3 μg/L, there were no participants that approached the level of action, and 3% ($n = 4$ Inuit) exceeded the level of concern (Table 4).

3.5. Cadmium

Cadmium was detected in nearly 85% of all maternal samples, ranging from 79% in the Dene/Métis group to

Table 3
Metals in maternal blood and trace elements in maternal plasma (μg/L)

Contaminant	Group	*N*	Min	Max	Arithmetic mean (SD)	Geometric mean (SD)	Detected (%)	Significant difference[a]	*P* value
Inorganic mercury	Caucasian	134	ND[b]	2.21	0.54 (0.38)	0.39 (0.66)	84.3	b	<0.0001
	Dene/Métis	92	ND	3.01	0.68 (0.54)	0.47 (1.09)	87	b	
	Other	13	0.20	0.80	0.47 (0.21)	0.42 (0.26)	100.0	b	
	Inuit	146	ND	4.61	1.09 (0.84)	0.77 (1.47)	91.1	a	
	Baffin	31	ND	4.61	1.68 (1.02)	1.39 (1.45)	96.8	a	0.0006
	Inuvik	31	ND	3.01	0.79 (0.65)	0.55 (1.17)	93.5	b	
	Kivalliq	17	ND	2.20	1.02 (0.59)	0.81 (1.04)	94.1	a, b	
	Kitikmeot	63	ND	4.21	0.99 (0.77)	0.69 (1.43)	85.7	b	
Methylmercury	Caucasian	134	0.00[c]	3.61	0.76 (0.78)	0.69 (1.97)	NA[d]	b	<0.0001
	Dene/Métis	92	0.00	4.01	1.05 (0.90)	0.80 (2.01)	NA	b	
	Other	13	0.00	3.01	1.29 (1.09)	1.15 (1.81)	NA	b	
	Inuit	146	0.00	29.29	4.32 (4.72)	2.87 (6.91)	NA	a	
	Baffin	31	0.00	29.29	8.07 (7.12)	5.97 (9.68)	NA	a	<0.0001
	Inuvik	31	0.00	21.26	2.93 (4.45)	1.76 (5.91)	NA	b	
	Kivalliq	17	0.40	9.73	3.87 (2.94)	2.67 (5.69)	NA	b	
	Kitikmeot	63	0.00	10.93	3.51 (2.49)	2.86 (3.28)	NA	b	
Total mercury	Caucasian	134	ND	4.21	1.26 (0.91)	0.87 (1.95)	88.1	c	<0.0001
	Dene/Métis	92	ND	6.02	1.72 (1.16)	1.35 (1.60)	97.8	b	
	Other	13	0.20	3.41	1.75 (1.20)	1.30 (2.14)	100	b, c	
	Inuit	146	ND	33.90	5.41 (5.38)	3.51 (8.30)	97.9	a	
	Baffin	31	ND	33.90	9.75 (8.05)	6.72 (17.68)	96.8	a	<0.0001
	Inuvik	31	0.60	24.27	3.72 (4.98)	2.13 (5.02)	100	b	
	Kivalliq	17	0.60	11.53	4.89 (3.32)	3.66 (5.75)	100	a, b	
	Kitikmeot	63	ND	12.74	4.50 (2.93)	3.42 (5.86)	96.8	b	
Cadmium	Caucasian	134	ND	8.54	1.11 (1.72)	0.43 (4.09)	79.1	b	<0.0001
	Dene/Métis	92	ND	5.86	1.51 (1.50)	0.65 (12.06)	82.6	b	
	Other	13	ND	3.15	0.76 (0.79)	0.36 (6.14)	84.6	b	
	Inuit	146	ND	7.76	2.50 (1.79)	1.50 (10.20)	91.1	a	
	Baffin	31	ND	6.18	2.65 (1.65)	1.65 (11.00)	87.1		0.25
	Inuvik	31	ND	7.11	2.23 (1.83)	1.00 (43.96)	87.1		
	Kivalliq	17	ND	7.72	2.40 (2.16)	1.43 (5.79)	88.2		
	Kitikmeot	63	ND	7.76	2.67 (1.76)	1.86 (5.47)	96.8		
Lead	Caucasian	134	2.07	58.0	24.08 (11.72)	20.58 (17.89)	96.3	b	<0.0001
	Dene/Metis	92	5.00	111.9	37.97 (24.30)	30.92 (29.08)	97.8	a	
	Other	13	5.00	43.5	26.04 (12.76)	21.92 (22.00)	92.3	a, b	
	Inuit	146	2.07	178.2	40.34 (27.21)	31.58 (38.28)	94.5	a	
	Baffin	31	5.00	120.2	51.23 (29.78)	41.67 (46.28)	96.8	a	0.0001
	Inuvik	31	2.07	101.5	29.61 (27.15)	18.77 (45.46)	77.4	b	
	Kivalliq	17	12.4	64.2	32.36 (16.20)	28.64 (18.08)	100	a, b	
	Kitikmeot	63	6.20	178.2	42.23 (26.68)	36.06 (26.11)	100	a	
Copper	Caucasian	132	985	3018	2056 (399)	2016 (420)	100		0.16
	Dene/Métis	93	216	3598	2249 (444)	2181 (704)	100		
	Other	13	1589	2907	2239 (419)	2202 (436)	100		
	Inuit	145	172	3472	2191 (508)	2112 (716)	100		
Selenium	Caucasian	132	80.0	184	124 (20)	123 (20)	100	a	0.039 (no significant pairwise differences)
	Dene/Métis	92	67.0	160	119 (20)	117 (22)	100	a	

Table 3 (*continued*)

Contaminant	Group	*N*	Min	Max	Arithmetic mean (SD)	Geometric mean (SD)	Detected (%)	Significant difference[a]	*P* value
	Other	13	97.0	156	129 (18)	128 (18)	100	a	
	Inuit	144	76.6	171	119 (18)	118 (18)	100	a	
	Baffin	31	98.7	152.01	118 (15)	117.6 (14)	100	a, b	0.0059
	Inuvik	30	88.1	151.0	119 (13)	118.0 (13)	100	a, b	
	Kivalliq	17	76.6	155.6	108 (20)	106.0 (19)	100	b	
	Kitikmeot	62	85.9	171.0	124 (20)	122.3 (20)	100	a	
Zinc (plasma)	Caucasian	132	340	5208	604 (420)	567 (167)	100		0.60
	Dene/Métis	91	268	1118	564 (118)	552 (119)	100		
	Other	13	268	922	603 (166)	579 (199)	100		
	Inuit	144	180	1438	569 (171)	544 (178)	100		

[a]*F*-test *P* value <0.0001 for overall significant difference; a, b, c comparisons are Tukey's *t*-test, where groups that do not have a letter in common are significantly different ($P<0.05$). For each contaminant and trace element, pairwise tests were done between ethnic groups, and then again between Inuit groups from the four regions.
[b]ND, not detected.
[c]Methylmercury was given a value of zero whenever inorganic Hg equaled or exceeded total Hg.
[d]NA, not applicable.

Table 4
Exceedances of guidelines for MeHg, Cd, and Pb

Ethnicity	Sample size		Methylmercury			Cadmium	Lead
	Maternal	Cord	Maternal $\geqslant 20\,\mu g/L$[a]	Maternal $>5.8\,\mu g/L$[b]	Cord $>5.8\,\mu g/L$[b]	Maternal $>5\,\mu g/L$[c]	Maternal $>100\,\mu g/L$[d]
Caucasian	134	134	0	0	1 (1%)	8 (6%)	0
Dene/Métis	92	86	0	0	4 (5%)	3 (3%)	2 (2%)
Other	13	13	0	0	0	0	0
Inuit	146	169	4 (3%)	34 (23%)	95 (56%)	15 (10%)	5 (3%)
Baffin	31	61	3 (10%)	18 (58%)	45 (74%)	4 (13%)	3 (10%)
Inuvik	31	30	1 (3%)	5 (16%)	6 (20%)	2 (6%)	1 (3%)
Kivalliq	17	16	0	4 (24%)	12 (75%)	3 (18%)	0
Kitikmeot	63	58	0	7 (11%)	32 (55%)	6 (10%)	1 (2%)
All participants	385	402	4 (1%)	34 (9%)	100 (25%)	26 (7%)	7 (2%)

[a]Health Canada's level of increasing concern (20–100 μg/L).
[b]USEPA revised BMDL (58 μg/L with 10-fold uncertainty factor = 5.8 μg/L cord blood MeHg). (US EPA, 2001).
[c]Level of concern defined here using conservative occupational exposure reference of 5 μg/L (OSHA, 1992).
[d]Level of action of 100 μg/L (10 μg/dL) (FPCOEH, 1994).

91% among Inuit participants. Overall, the Cd GM was significantly greater for Inuit participants than for the rest of the ethnic groups, which were not significantly different from each other ($P<0.0001$) (Table 3). More than half of all participants were smokers. The Cd GM was ninefold greater in participants that smoked relative to participants that reported themselves as nonsmokers (Table 5).

Among all participants, the blood Cd GM in moderate smokers (1–8 cigarettes/day) and in heavy smokers (>8 cigarettes/day) was 7.4-fold higher and 12.5-fold higher than nonsmokers, respectively. The pattern of low-to-high cadmium concentrations reflect the smoking habits as reported by each of the ethnic groups, which is described in more detail in the following section.

Health Canada does not have blood guidelines for women of reproductive age for Cd; however, 5 μg/L was used as the level of concern for women in this study because it is the most conservative occupational limit (OSHA, 1992). This level was exceeded by 7% of all participants, including 10% of Inuit and 3% of Dene/Métis participants (Table 4).

3.6. Lead

Lead was detected in over 90% of the samples in all ethnic groups (Table 3). The Pb GM was significantly higher in Dene/Métis (30.9 μg/L or 3.1 μg/dL, SD = 29.1) and Inuit (31.6 μg/L, SD = 38.3) participants than in the Caucasian group (20.6 μg/L, SD = 17.9) ($P<0.0001$). GM levels were significantly

Table 5
Mean maternal Cd concentration as a function of self-reported tobacco use (all participants)

	Cadmium (μg/L)					
	N	Min	Max	Arithmetic mean (SD)	Geometric mean (SD)	% detected
Smokers	192	ND[a]	8.54	2.91 (1.75)	2.24 (4.08)	98
Nonsmokers	191	ND	6.55	0.52 (0.69)	0.25 (1.91)	71
Moderate (1–8 cigarettes/day)	109	ND	6.18	2.43 (1.35)	1.86 (3.9)	97
Heavy (>8 cigarettes/day)	80	0.4	8.54	3.66 (1.95)	3.13 (2.44)	100

[a]ND, not detected.

Table 6
Summary of umbilical cord metals (blood) and trace element (plasma) results for all cord samples (μg/L)

Contaminant	*N*	Minimum	Maximum	Arithmetic mean	Geometric mean	Detection limit	Detected (%)
Blood							
Inorganic mercury	402	ND[a]	5.6	0.83	0.54	0.2	88.3
Methylmercury[b]	402	0.0[c]	70.2	4.9	2.5	NA	NA[d]
Total mercury	402	ND	75.8	5.8	2.7	0.2	96.5
Lead	402	2.1	155	28	21	10	95.8
Cadmium	402	ND	7.5	0.2	0.08	0.2	26.4
Plasma							
Copper	382	89	2446	408	357	65	100
Selenium	381	43	142	79	78	15	100
Zinc	378	275	5491	1097	986	200	100

[a]ND, not detected.
[b]Methylmercury calculated as difference between total Hg and inorganic Hg.
[c]Methylmercury was given a value of zero whenever inorganic Hg equaled or exceeded total Hg.
[d]NA, not applicable.

higher in participants from the Baffin and Kitikmeot Regions relative to Inuvialuit ($P<0.0001$) (Table 3).

The GM concentrations for all ethnic groups were well below 100 μg/L, Health Canada's level of action at a population level (Van Oostdam et al., 1999); however, there were seven individuals whose Pb results exceeded 100 μg/L, and two other participants were close to this level.

3.7. Cu, Se, and Zn

Plasma Cu arithmetic means ranged from 2056 μg/L (SD = 399) for Caucasian participants to 2249 μg/L (SD = 444) for the Dene/Métis group. While group means were all within the acceptable range of 1180–3200 μg/L at term for plasma Cu (AMAP, 2003), there was considerable individual variability, particularly among Inuit and Dene/Métis participants, in whom minimum values were 172 and 216 μg/L, respectively, and maximum values were 3472 and 3598 μg/L, respectively (Table 3). GM plasma Zn ranged from 544 μg/L (SD = 178) for Inuit to 579 μg/L (SD = 198) for Other nonaboriginal participants, and individual values ranged from 180 to 5208 μg/L for an Inuk and Caucasian participant, respectively (Table 3). These mean levels were below the accepted reference interval of 700–1500 μg/L for plasma Zn (AMAP, 2003) and not significantly different between ethnic groups ($P = 0.60$). Participants had not fasted prior to sampling and were not sampled at the same time of the day, which may have introduced variability into the Zn results. This differs from the Cu and Se results, which are not sensitive to these sampling factors. The comparison of ethnic groups in the ANOVA model was not significant for Cu and Zn (Table 3). For Se, although the ANOVA showed, overall, a significant difference between ethnic groups, there were no significant pairwise differences in mean Se levels between ethnic groups, which ranged from 117 to 128 μg/L (Table 3). The regression of Se on Hg indicated that there was no significant relationship between methylmercury and selenium for the range of MeHg exposures in this study (regression not shown). Among Inuit participants, mean Se levels were significantly higher in the Kitikmeot Region than in the Kivalliq Region ($P = 0.006$) (Table 3).

3.8. Umbilical cord Hg, Cd, Pb, Cu, Se, Zn

Umbilical cord blood results for all samples are summarized in Table 6. Overall, there were slightly more

Table 7
Metals (blood) and trace elements (plasma) in cord blood (μg/L)

Contaminant	Group	N	Min	Max	Arithmetic mean (SD)	Geometric mean (SD)	Detected (%)	Significant difference[a]	P value
Inorganic mercury	Caucasian	134	ND[b]	2.40	0.52 (0.36)	0.40 (0.55)	90.3	b	<0.0001
	Dene/Métis	86	ND	1.40	0.54 (0.33)	0.39 (0.83)	86	b	
	Other	13	ND	5.10	0.65 (1.35)	0.29 (0.81)	69.2	b	
	Inuit	169	ND	5.61	1.23 (1.00)	0.83 (1.88)	89.3	a	
	Baffin	61	0.40	5.61	1.77 (1.10)	1.50 (1.14)	100	a	<0.0001
	Inuvik	30	ND	3.95	0.79 (0.87)	0.47 (1.38)	83.3	c	
	Kivalliq	16	0.20	2.80	1.30 (0.77)	1.07 (1.09)	100	a, b	
	Kitikmeot	58	ND	2.81	0.91 (0.76)	0.57 (1.62)	77.6	b, c	
Methylmercury	Caucasian	134	0.00[c]	11.64	1.27 (1.35)	1.14 (1.33)	NA[d]	b	<0.0001
	Dene/Métis	86	0.00	7.63	1.67 (1.67)	1.19 (2.10)	NA	b	
	Other	13	0.20	5.22	2.29 (2.20)	1.24 (5.28)	NA	b	
	Inuit	169	0.00	70.21	9.73 (10.27)	6.16 (14.92)	NA	a	
	Baffin	61	1.80	70.21	14.81 (13.28)	10.58 (15.15)	NA	a	<0.0001
	Inuvik	30	0.00	34.57	4.86 (6.96)	2.81 (8.60)	NA	c	
	Kivalliq	16	0.60	24.08	9.97 (7.54)	6.76 (17.41)	NA	a, b	
	Kitikmeot	58	0.60	25.37	7.41 (5.91)	5.35 (8.19)	NA	b	
Total mercury	Caucasian	134	ND	12.84	1.77 (1.48)	1.22 (2.80)	91.0	b	<0.0001
	Dene/Métis	86	ND	8.83	2.19 (1.78)	1.62 (2.29)	97.7	b	
	Other	13	0.40	5.50	2.95 (2.21)	2.01 (4.29)	100	b	
	Inuit	169	0.40	75.82	10.96 (11.16)	6.96 (15.64)	100	a	
	Baffin	61	2.40	75.82	16.58 (14.31)	12.20 (15.63)	100	a	<0.0001
	Inuvik	30	0.40	38.52	5.65 (7.74)	3.08 (8.76)	100	c	
	Kivalliq	16	1.00	26.88	11.27 (8.27)	8.00 (16.32)	100	a, b	
	Kitikmeot	58	1.20	27.98	8.33 (6.43)	6.26 (7.90)	100	b	
Cadmium	Caucasian	134	ND	2.38	0.22 (0.24)	0.10 (0.61)	39.6	a	0.031
	Dene/Métis	86	ND	0.64	0.15 (0.10)	0.06 (0.34)	23.3	b	
	Other	13	ND	0.37	0.14 (0.08)	0.07 (0.38)	23.1	a, b	
	Inuit	169	ND	7.54	0.20 (0.62)	0.08 (0.28)	17.8	a, b	
	Baffin	61	ND	7.54	0.31 (1.02)	0.08 (0.32)	14.8	a	<0.0001
	Inuvik	30	ND	0.27	0.11 (0.03)	0.03 (0.10)	3.3	b	
	Kivalliq	16	ND	0.10	0.10 (0.00)	0.08 (0.11)	0	a	
	Kitikmeot	58	ND	0.50	0.17 (0.11)	0.12 (0.21)	32.8	a	
Copper	Caucasian	125	89	1010	390 (151)	363 (156)	100		0.80
	Dene/Métis	82	114	1646	387 (211)	350 (171)	100		
	Other	14	184	655	421 (148)	395 (169)	100		
	Inuit	161	89	2446	432 (372)	353 (261)	100		
Lead	Caucasian	134	2	64.2	18.1 (9.6)	15.2 (14.4)	95.5	c	<0.0001
	Dene/Métis	86	2.1	114.0	28.3 (20.7)	21.8 (26.6)	96.5	a, b	
	Other	13	2.1	37.3	17.8 (10)	14.4 (16.8)	100	b, c	
	Inuit	169	4.1	155.4	35.2 (26.1)	27.3 (31)	95.3	a	
	Baffin	61	10.4	132.6	43.2 (26.4)	35.7 (31.5)	100.0	a	<0.0001
	Inuvik	30	4.1	134.7	24.7 (30.8)	15.0 (29.9)	73.3	b	
	Kivalliq	16	8.3	74.6	29.2 (18.1)	24.4 (21.1)	100	a, b	
	Kitikmeot	58	7.2	155.4	33.8 (23.1)	28.9 (20.0)	100	a	
Selenium	Caucasian	125	43.4	142.0	87 (18)	86 (18)	100	a	<0.0001
	Dene/Métis	81	45.0	107.0	75 (14)	74 (14)	100	b	
	Other	14	61.0	116.0	88 (13)	87 (14)	100	a	
	Inuit	161	52.1	120.1	74 (12)	73 (12)	100	b	
	Baffin	54	57.7	120.1	77 (13)	76 (12)	100	a	0.010
	Inuvik	30	54.0	95.0	73 (12)	72 (12)	100	a, b	
	Kivalliq	15	52.1	84.5	66 (9)	66 (10)	100	b	
	Kitikmeot	58	53.0	103.0	73 (11)	72 (11)	100	a, b	

Table 7 (*continued*)
Metals (blood) and trace elements (plasma) in cord blood (μg/L)

Contaminant	Group	*N*	Min	Max	Arithmetic mean (SD)	Geometric mean (SD)	Detected (%)	Significant difference[a]	*P* value
Zinc	Caucasian	124	392	4608	1172 (614)	1091 (395)	100	a	0.0003
	Dene/Métis	82	307	5491	1173 (1610)	986 (481)	100	a, b	
	Other	14	830	2987	1181 (554)	1107 (401)	100	a, b	
	Inuit	158	275	5491	991 (622)	902 (385)	100	b	

[a] *F*-test *P* value <0.0001 for overall significant difference; a, b, c comparisons are Tukey's *t*-test, where groups which do not have a common letter are significantly different ($P<0.05$). For each contaminant and trace element, pairwise tests were done between ethnic groups, and then again between Inuit groups from the four regions.
[b] ND, not detected.
[c] Methylmercury was given a value of zero whenever inorganic Hg equaled or exceeded total Hg.
[d] NA, not applicable.

(4%) umbilical cord blood samples ($n = 402$) than maternal samples ($n = 386$). The results reported in this section include all cord blood samples. The following section reports the relationship between maternal and cord results at the time of sampling for paired samples only (maternal and cord blood from the same participant).

Altogether, Pb and THg were detected in more than 95% of all cord blood samples, with GMs of 21 μg/L and 2.7 μg/L, respectively, and Cd was detected in 26% of all cord samples, with a GM of 0.08 μg/L (Table 6). GM cord MeHg ranged from 1.14 μg/L (SD = 1.33) in Caucasians to 6.16 μg/L (SD = 14.9) in Inuit participants, with the mean MeHg concentration significantly higher in Inuit samples than in the rest of the ethnic groups ($P<0.0001$) (Table 7). There was considerable individual variability between Inuit cord samples, with values ranging from 0.0 to 70 μg/L, as well as regional differences, with MeHg GM for participants from the Baffin Region significantly higher than the MeHg GM for Inuvialuit (Inuit participants from the Inuvik Region) ($P<0.0001$) (Table 7). Umbilical cord blood levels of Cd were low for all ethnic groups, ranging from 5% to 20% of maternal values. The cord blood Pb GM ranged from 14.4 μg/L (SD = 16.8) in the Other nonaboriginal group to 27.3 μg/L (SD = 31.0) in the Inuit group, with the GM for Inuit significantly higher than that reported for Caucasians and the other group ($P<0.0001$). Among Inuit participants, the GMs were significantly higher in the Kitikmeot and Baffin Regions than in the Inuvik Region ($P<0.0001$), which is the same pattern as that seen in maternal samples. Lead was detected in 73% of cord samples from the Inuvik Region and 100% of samples from the other Inuit regions.

There were no significant differences in Cu GM levels between ethnic groups, with umbilical cord blood Cu means ranging from 350 μg/L for Dene/Métis to 395 μg/L for the Other nonaboriginal group; individual values ranged from 89 to 2446 μg/L (Table 7). Minimum Cu values from each of the ethnic groups ranged from 89 to 184 μg/L, and were all below the 200–700 μg/L accepted range between 0 and 6 months of age (AMAP, 2003). The mean Zn value of 1091 μg/L for Caucasian participants was significantly higher than the mean of 902 μg/L for Inuit participants ($P<0.0003$). Mean cord Se values were significantly higher in the Caucasian and Other nonaboriginal groups than they were in the Dene/Métis and the Inuit groups ($P<0.0001$).

3.9. *Relationship between maternal and umbilical cord blood levels*

Maternal concentrations of Cd, Pb, Cu, and Se were, on average, significantly greater than cord concentrations (all $P<0.0001$), and cord concentrations were significantly greater, on average, than maternal concentrations for MeHg, THg, and Zn (all $P<0.0001$). There were no significant differences between concentrations of IHg in maternal and cord blood.

A preliminary look at the relationship between metals in umbilical cord blood and maternal blood was conducted by describing the ratios of cord blood:maternal blood for paired samples and also by calculating simple linear regressions with paired samples from all participants who donated both a maternal and cord blood sample. Correlations were also calculated between log-transformed cord and log-transformed maternal paired data.

The THg ratio of cord blood:maternal blood for all participants ranged from 0.44 to 4.5 with a GM of 1.4, and the MeHg ratio ranged from 0.15 to 10.3 with a mean for all participants of 1.6 (Table 8). For THg, there was a difference of 50% in the range of cord mercury relative to maternal mercury, with Dene/Métis and Caucasians participants presenting the lowest mean ratio (1.2) and Inuit participants the highest (1.7). This difference increased to 70% for MeHg, with GM cord:maternal ratios of 1.3 and 2.0 for Dene/Métis and Inuit participants, respectively. All groups had highly significant cord to maternal correlations for THg

Table 8
Cord blood:maternal blood ratios (calculated using individual cord:maternal pairs)

Contaminant	Ethnicity	N	Min	Max	Arithmetic mean	Arithmetic SD	Geometric mean	Geometric SD	Cor[a,b]
Total Hg (THg)	All	320	0.44	4.51	1.49	0.56	1.40	0.57	0.95
	Caucasian	101	0.50	4.00	1.34	0.58	1.24	0.54	0.84
	Dene/Métis	78	0.44	2.67	1.26	0.46	1.19	0.45	0.87
	Other	11	0.88	4.51	1.73	1.00	1.56	0.80	0.89[c]
	Inuit	130	0.67	3.13	1.73	0.45	1.67	0.48	0.97
	Baffin	28	1.33	2.56	1.85	0.35	1.82	0.35	0.97
	Inuvik	29	0.67	2.33	1.47	0.37	1.42	0.42	0.97
	Kivalliq	15	1.25	2.91	2.10	0.47	2.05	0.52	0.98
	Kitikmeot	54	0.95	3.13	1.74	0.42	1.70	0.43	0.95
Methylmercury	All	294	0.15	10.3	1.86	1.01	1.64	1.05	0.90
	Caucasian	87	0.30	5.51	1.75	1.03	1.49	1.12	0.72
	Dene/Métis	73	0.15	6.00	1.56	0.92	1.33	1.07	0.74
	Other	9	0.60	3.11	1.74	0.69	1.60	0.86	0.89[c]
	Inuit	125	0.60	10.3	2.11	1.02	1.97	0.76	0.94
	Baffin	28	1.27	3.76	2.10	0.54	2.04	0.54	0.96
	Inuvik	25	0.60	7.00	1.92	1.17	1.73	0.86	0.93
	Kivalliq	15	1.50	3.28	2.34	0.52	2.28	0.58	0.98
	Kitikmeot	54	0.80	3.69	2.01	0.52	1.94	0.57	0.94
Inorganic mercury	All	274	0.19	4.00	1.01	0.47	0.92	0.44	0.83
	Caucasian	96	0.19	4.00	0.95	0.56	0.84	0.49	0.64
	Dene/Métis	63	0.40	3.00	0.94	0.50	0.86	0.40	0.73
	Other	8	0.50	1.33	0.98	0.29	0.94	0.34	0.75[d]
	Inuit	107	0.33	3.00	1.10	0.36	1.04	0.37	0.89
	Baffin	28	0.60	1.75	1.17	0.29	1.13	0.31	0.88
	Inuvik	24	0.33	3.00	0.98	0.52	0.89	0.45	0.81
	Kivalliq	14	1.00	1.70	1.31	0.27	1.29	0.28	0.93
	Kitikmeot	37	0.50	1.60	1.04	0.28	1.01	0.31	0.91
Lead	All	324	0.06	9.00	0.87	0.65	0.76	0.49	0.73
	Caucasian	115	0.06	3.00	0.83	0.47	0.72	0.50	0.62
	Dene/Métis	77	0.14	5.00	0.81	0.55	0.72	0.39	0.79
	Other	10	0.14	1.67	0.79	0.42	0.67	0.61	0.64[e]
	Inuit	122	0.17	9.00	0.96	0.83	0.82	0.52	0.69
	Baffin	28	0.45	2.05	0.99	0.39	0.92	0.37	0.84
	Inuvik	20	0.22	9.00	1.25	1.88	0.81	1.12	0.57[f]
	Kivalliq	15	0.38	2.29	0.97	0.49	0.88	0.47	0.73
	Kitikmeot	55	0.17	2.00	0.84	0.32	0.77	0.42	0.66

[a]Cor, correlation between log-transformed cord and log-transformed maternal values (Pearson correlation coefficient).
[b]All correlations highly significant ($P<0.0001$), except as noted.
[c]$P<0.001$.
[d]$P=0.017$.
[e]$P=0.023$.
[f]$P<0.05$.

and MeHg ranging from 0.72 to 0.97 (all $P<0.0001$). Pb cord blood:maternal blood ratios ranged from 0.67 to 0.82 for Other nonaboriginals and Inuit, respectively, with an overall mean ratio of 0.76 and correlation coefficient of 0.73 ($P<0.0001$) (Table 8). The highly significant correlations between paired maternal and cord THg (Pearson's $r=0.95$; $P<0.0001$) and MeHg (Pearson's $r=0.90$; $P<0.0001$) indicate that either maternal blood or cord blood can be used as surrogates of prenatal mercury exposure, particularly during the third trimester. These very high Hg correlations are consistent with those reported for Inuit from Greenland (Bjerregaard and Hansen, 2000) and Inuit from Nunavik, Canada (Muckle et al., 2001b), likely reflecting similar sources and dietary patterns of traditional food consumption.

Simple linear regressions on log-transformed values indicated that, for all participants with both a detected maternal and a detected cord value, there was considerable variation between metals in the relationship between paired fetal blood and maternal blood concentrations at the time of sampling (Table 9). Slopes ranged from 0.10 for cadmium, indicating low fetal cadmium exposure relative to maternal exposure (data not shown), to 1.11 for total mercury, indicating a higher fetal exposure than maternal exposure. Tests of regression differences between groups indicated that, for THg and MeHg, slopes were significantly different

Table 9
Regression of log-maternal vs. log cord blood (both values detected)

Contaminant	Ethnic group	Intercept		Slope		r^2
		N	Estimate	Estimate	*P* value	
Lead	All participants	324	0.36	0.81	<0.0001	0.53
	Caucasian	115	0.68	0.67	<0.0001	0.38
	Inuit	122	0.88	0.70	<0.0001	0.48
	Métis/Dene	77	−0.19	0.96	<0.0001	0.63
	Other	10	−0.11	0.91	0.033	0.41
Methylmercury	All participants	294	0.49	1.01	<0.0001	0.81
	Caucasian	87	0.33	0.69	<0.0001	0.51
	Inuit	125	0.71	0.97	<0.0001	0.89
	Métis/Dene	73	0.27	0.84	<0.0001	0.55
	Other	9	0.45	1.06	0.0005	0.80
Total mercury	All participants	320	0.26	1.11	<0.0001	0.90
	Caucasian	101	0.23	0.93	<0.0001	0.71
	Inuit	130	0.35	1.12	<0.0001	0.94
	Métis/Dene	78	0.20	0.92	<0.0001	0.76
	Other	11	0.49	0.84	0.0001	0.79
Inorganic mercury	All participants	274	0.03	0.87	<0.0001	0.68
	Caucasian	96	0.06	0.58	<0.0001	0.41
	Inuit	107	0.03	0.97	<0.0001	0.80
	Métis/Dene	63	0.05	0.58	<0.0001	0.53
	Other	8	0.34	0.31	0.03	0.56

($P = 0.0003$ and 0.005, respectively) and intercepts were also significantly different (both $P<0.0001$). For Pb, slopes were not significantly different ($P = 0.07$); however, intercepts were ($P<0.0001$). These regressions warrant further investigation, as preliminary work indicates that absolute maternal concentrations may influence regression parameters (Van Oostdam et al., 2001).

Between metals, Pearson correlation coefficients were positively correlated, with lead more highly correlated with total mercury in cord blood ($r = 0.46$) than maternal blood ($r = 0.37$) (data not shown).

3.10. Cigarette use, calculated traditional food consumption, and cadmium levels

Maternal Cd GMs are described as a function of tobacco use (cigarettes) and calculated traditional food consumption (Fig. 2). For four of the five participating regions, traditional food use was not quantified systematically. Rather, questions were asked as part of a general lifestyle survey to provide an overall indication of some of the species consumed and, for some species, various tissues. Accordingly, for this analysis of the relative contributions of cigarettes and traditional foods to Cd exposure, traditional food consumption was categorized as high, moderate, or none based on the calculated median value of 115 g/day to facilitate comparisons between groups as previously described.

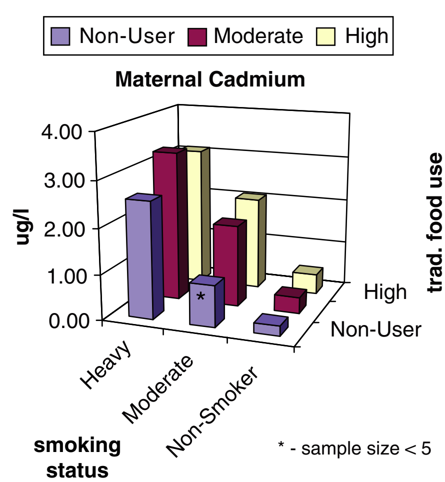

Fig. 2. Cigarette use, traditional food consumption and maternal cadmium levels.

Overall, there were effects of both smoking and traditional food use on maternal Cd levels. The effects of smoking predominated, as there were marked dose–response increases in maternal Cd levels for nonsmoker to moderate smoker (⩽8 cigarettes/day) to heavy smoker (>8 cigarettes/day) for all three traditional food consumption categories. The small effect of traditional food use on maternal Cd levels can be seen in Fig. 2. This was particularly so for nonsmokers, as there was only a very moderate increase in maternal cadmium across the "nonuser" to "high" traditional food consumers. For all participants combined, the three smoking categories had significantly different maternal cadmium levels ($P<0.0001$).

4. Discussion

4.1. Mercury

Mercury is a toxic metal that originates from natural and anthropogenic sources and has been identified as a priority contaminant in the circumpolar north (AMAP, 2003), including the Canadian Arctic (Van Oostdam et al., 2003). Hg was detected in more than 97% of maternal blood ($n = 251$) and cord blood ($n = 268$) samples from Dene/Métis, Inuit, and Other nonaboriginal participants from the NWT and Nunavut in the present study.

The United Nations Environment Programme's Global Mercury Assessment attests to international concerns about environmental mercury (UNEP, 2002). MeHg is ubiquitous, with nearly all people having some low-level exposure. Long-range atmospheric transport mechanisms distribute anthropogenic and naturally occurring Hg to regions distant from their origins, including the circumpolar north. The Hg that is mobile in the environment includes gaseous elemental Hg, primarily from air emissions resulting from fossil fuel combustion, and to a lesser extent gaseous inorganic ionic Hg and species bound to emitted particles (UNEP, 2002). Once deposited, mercury can become methylated and hence biologically available. MeHg biomagnifies and bioaccumulates in the environment, particularly in aquatic environments, and as such can be found in elevated levels in freshwater and marine fish as well as marine mammal species (AMAP, 2003).

Methylmercury crosses the placental barrier, is generally present at higher concentrations in fetal blood than in maternal blood, and is able to penetrate the fetal blood–brain barrier (WHO, 1990). It has been quantified in several species traditionally consumed by Inuit and Dene/Métis in Nunavut and the NWT. Results from extensive sampling of freshwater fish and marine mammals and fish in multiple locations across the Canadian Arctic indicate that there is high lake-to-lake variability in mercury levels in fish and that, in general, levels of mercury in freshwater and marine organisms have not changed much over the past 20–30 years (Van Oostdam et al., 2003). An exception are beluga from the Beaufort Sea and Hudson Bay, in which mercury levels are increasing, perhaps in part as a result of the effects of global climate change (Van Oostdam et al., 2003).

While neurodevelopmental effects of acute, accidental prenatal exposure to methylmercury were documented for Minamata and Niigata, Japan in the 1950s and Iraq in the 1970s, effects from chronic, low-dose prenatal exposure have been more difficult to elucidate. Longitudinal cohort studies over the past decade have resulted in two positive studies and one negative study, and discussions will likely be ongoing for some time about the lowest level of exposure that may cause adverse health effects (e.g., Stern et al., 2004).

In the Faroe Islands, a cohort of 917 Faroese children with a (geometric) mean cord blood MeHg exposure of 22.9 μg/L, primarily from maternal consumption of pilot whales (Grandjean et al., 1992), was determined to have neuropsychological effects in the domains of language, memory, and attention at 7 years of age (Grandjean et al., 1997). In the Republic of the Seychelles, where oceanic fish are the main source of MeHg, children from a cohort of 711 mother/child pairs were evaluated at 66 ± 6 months with no reported adverse outcomes from prenatal or postnatal exposure to MeHg (Davidson et al., 1998). A study in New Zealand with design and exposure similar to those of the Seychelles study, however, reported decreased performance on scholastic and psychological tests associated with high prenatal MeHg exposure (Crump et al., 1998). Results from these studies were included in a review conducted by the United States National Research Council (US NRC) at the request of the US Environmental Protection Agency (US EPA) to investigate the toxicological effects of MeHg in relation to the review of MeHg exposure reference dose recommendations. Based on cord blood as the biomarker to detect adverse effects in the Faroe Islands study (Grandjean et al., 1999), and the Boston Naming Test deemed as sufficiently reliable, the US NRC committee's preferred estimate of the benchmark dose lower limit (BMDL) was 58 μg/L (ppb) MeHg in cord blood (US NRC, 2000). "A benchmark dose level is the lowest dose, estimated from the modeled data, that is expected to be associated with a small increase in the incidence of adverse outcome (typically in the range of 1–10%). The BMDL of 58 ppb is calculated statistically and represents the lower 95% confidence limit on the dose (or biomarker concentration) that is estimated to result in a 5% increase in the incidence of abnormal scores on the Boston Naming Test" (US NRC, 2000). In addition to this value of 58 μg/L, the committee also recommended an uncertainty factor of no less than 10, which is a composite to include biological variability and database insufficiencies, and which corresponds to 5.8 μg/L MeHg in cord blood (US NRC, 2000). The US EPA incorporated these recommendations in its MeHg oral reference dose assessment (US EPA, 2001). In this assessment, it was noted that "EPA has chosen not to make a numerical adjustment between cord-blood and maternal-blood mercury. At this time the relationship between cord-blood and maternal-blood mercury is considered subject to variability and uncertainty, and is to be included in the determination of the uncertainty factor" (US EPA, 2001).

Mean ratios of cord blood:maternal blood (calculated from individual values) from paired samples from all participants in the present dataset ranged from 1.3 to 2.0 for MeHg , and from 1.2 to 1.7 for THg, with some differences between ethnic groups. The ratios from the present study fall within the range of those calculated from 10 studies meeting specific selection criteria by Stern and Smith (2003).

In relation to the revised US EPA value, 56% of Inuit and 5% of Dene/Métis cord blood samples in the present study were greater than 5.8 μg/L MeHg. This is a considerable increase from the 3% of Inuit maternal samples that fell within the current Health Canada MeHg guideline of a level of concern for increasing risk of 20–100 μg/L.

There were regional differences for Inuit participants with results exceeding 5.8 μg/L MeHg, as reported in Table 4. These differences ranged from 11% to 58% for maternal samples from Kitikmeot ($n = 7$) and Baffin ($n = 18$) participants, respectively, and from 20 to 74 and 75% of Inuit cord samples from Inuvik ($n = 6$) and the Baffin ($n = 45$) and Kivalliq ($n = 12$) Regions, respectively. Similar patterns of exceedances were evident in the Nuuk Region of Greenland, where 3% of mothers exceeded 20 μg/L and 27% exceeded 5.8 μg/L MeHg, however, in two other regions in Greenland maternal exceedances of 5.8 μg/L were 68% and 80% (AMAP, 2003). In two communities in the state of Alaska in the USA, maternal blood Hg exceeding 5.8 μg/L ranged from 0% of women from Barrow, where residents are consumers of terrestrial mammals and bowhead whales (plankton feeders), to 48% of women from Bethel, where residents consume freshwater fish and some marine mammals (AMAP, 2003). These circumpolar data highlight the importance of ongoing monitoring as well as international efforts to reduce global Hg emissions.

Elsewhere in northern Canada, mean maternal and cord blood levels of 10.4 and 18.5 μg/L, respectively, have been reported in Nunavik (Northern Quebec) for a prospective longitudinal study investigating the effects of MeHg and PCB exposure on infant development (Table 10; Muckle et al., 2001b). These mean levels in Nunavik are 2.6- and 3-fold higher than the mean values for the Inuit cord and maternal results, respectively, described in the present study, however, they are only 1.5-fold higher than the mean maternal and cord levels reported for the Baffin Region of Nunavut.

Mean Hg levels in maternal samples from other circumpolar regions are summarized for comparative purposes in Table 10. These indicate that mean levels in Caucasian, Dene/Métis, and Other nonaboriginal participants in the present study are comparable to means from nonindigenous residents in other northern areas. Also, mean Hg levels in Inuit from Greenland and Nunavik are higher than those found in Inuit in the present study (Table 10). The higher blood levels in Inuit are associated with the consumption of muscle and fatty skin (muktuk) from marine mammals and are a function of both the frequency of consumption and the tissue levels in various species from various locations (AMAP, 2003; Chan et al., 1995; Kuhnlein and Chan, 2000).

Temporally, there has been a decrease in Hg exposure of NWT and Nunavut residents, with 56% ($n = 844$) of Inuit and 19% ($n = 137$) of Dene/Métis men and women surveyed from 1972 to 1989 having blood methylmercury levels ranging from 20 to 99 μg/L (Wheatley, 1994), in comparison to the 3% and 0% of Inuit and Dene/Métis women in this range in the present study. While the data are not directly comparable due to differences in sampling protocol (including repeat sampling of the same individuals with high exposures and the inclusion of men and older women in the earlier survey as opposed to only women of reproductive age), the decreased exposure is clear. These differences in exposures may be attributed to changes in traditional diet, changes in concentrations of Hg in species traditionally consumed, and different sampling protocol or, more likely, a combination of these factors.

Mean inorganic Hg levels from Inuit were significantly higher in both maternal and cord blood relative to the rest of the ethnic groups, with mean levels in the Baffin and Kivalliq participants higher than those from the Kitikmeot and Inuvik Regions ($P < 0.001$). These results suggest that the consumption of species contributing to increased methylmercury concentrations also contributes to elevated inorganic levels in these groups, given that inorganic mercury concentrations do not increase following the consumption of a fish meal over a short time period (Kershaw et al., 1980). Lockhart et al. (1999) has also shown that a form of inorganic mercury, mercuric selenide, is the major form of mercury in beluga organs, an important part of the diet of Inuit in some areas. There is very little known at present about the developmental neurotoxicity of inorganic mercury, particularly in relation to prenatal/early postnatal exposure and early childhood development (Davidson et al., 2004).

Expectations are that Hg will continue to be a contaminant of concern, not only in the Arctic but globally, and that in the circumpolar north Hg levels will continue to increase for at least the next decade (AMAP, 2003; UNEP, 2002). The effects of global climate change may increase the bioavailability of mercury (AMAP, 2003). Modeling the flow of MeHg in the Faroe Islands suggested that MeHg increased in the marine environment under present conditions as well as climate change scenarios and increased more as a result of fishing mortalities, and these two effects were cumulative in

Table 10
Comparative total mercury concentrations (μg/L)

Location or ethnic group	Geometric mean	Sample type	Years collected	N	Reference	Comments
Canada						
Caucasian	0.87	Maternal	1994–1999	134	This study	(Cord blood, 1.22 μg/L; $n = 134$)
Dene/Métis	1.35	Maternal	1994–1999	92	This study	(Cord blood, 1.62 μg/L; $n = 86$)
Other	1.30	Maternal	1994–1995	13	This study	(Cord blood, 2.01 μg/L; $n = 13$)
Inuit	3.51	Maternal	1994–1999	146	This study	(Cord blood, 6.96 μg/L; $n = 169$)
Baffin Inuit	6.72	Maternal	1994–1999	31	This study	(Cord blood, 12.20 μg/L; $n = 61$)
Inuvik inuit (Inuvialuit)	2.13	Maternal	1994–1999	31	This study	(Cord blood, 3.08 μg/L; $n = 30$)
Kivalliq Inuit	3.66	Maternal	1994–1999	17	This study	(Cord blood, 8.00 μg/L; $n = 16$)
Kitikmeot Inuit	3.42	Maternal	1994–1999	63	This study	(Cord blood, 6.26 μg/L; $n = 58$)
Nunavut	17.2	Maternal	1978–1988	61	Wheatley (1994)	Inuit
Western NWT	14.36	Cord	1978–1982	5	Wheatley (1994)	Dene
	10.66	Maternal	1982–1983	76	Wheatley (1994)	Dene
Nunavik (N. Quebec)	12.1	Cord	1993–1995	299	Dewailly et al. (1996)	Inuit
	18.5	Cord	1996–2000	95	Muckle et al. (2001b)	Inuit
	10.4	Maternal	1996–2000	130	Muckle et al. (2001b)	Inuit
S. Quebec	0.97	Cord	1993–1995	1109	Rhainds et al. (1999)	Nonindigenous
Ontario	2.2	Adults	1992–1993	176	Kearney et al. (1995)	Fish eaters (Total Hg)
Greenland						
Disko Bay	12.8	Maternal	1994–1996	175	Bjerregaard and Hansen (2000)	Inuit
Disko Bay	25.3	Cord	1994–1996	160	Bjerregaard and Hansen (2000)	Inuit
Ilullisat	12.4	Maternal	1999–2000	29	Deutch in AMAP (2003)	Inuit
Finland	1.4	Maternal	1996–1998	130	Soininen et al. (2001) in AMAP (2003)	
Russia (Siberia)						
Taymir	2.7	Maternal	1995–1996	18	AMAP (2003)	Indigenous
Yamal	2.9	Maternal	1996–1998	12	AMAP (2003)	Indigenous
Norilsk	1.4	Maternal	1995–1996	49	AMAP (2003)	Nonindigenous
USA (Alaska)						
Bethel	5.5	Maternal	2000	23	Berner (2000), in AMAP (2003)	Inuit (consumers of freshwater fish and some marine mammals)
Barrow	1.3	Maternal	2000	23	Berner (2000) in AMAP (2003)	Inuit (consumers of terrestrial mammals and bowhead whales)

simulations that included combined effects (Booth and Zeller, 2005).

In any population, characterizing effects related to exposure to mixtures of contaminants is complex (Carpenter et al., 2002). In the Arctic, the exposure of Arctic populations to mixtures of organochlorine and metal contaminants will continue to challenge public health authorities, regulatory agencies, researchers, and communities and will require continuing monitoring of populations at risk as well as ongoing communications. Important areas of continued research include investigating nutritional factors that may influence the toxicity of Hg, ongoing monitoring of traditional food species consumed by Inuit and Dene/Métis, ongoing monitoring of populations at risk, and research to characterize the effects of contaminant mixtures. Public health recommendations that include increased consumption of traditional species with lower MeHg concentrations for women of reproductive age, and the effectiveness of ongoing communications about the benefits and risks of consuming various traditional food species, also need to be evaluated (Van Oostdam et al., 2003; Chapman and Chan, 2000; Kuhnlein and Chan, 2000).

4.2. Cadmium

Results from the present study indicate that tobacco use was widespread among Inuit and First Nations participants from Nunavut and the NWT. The percentage of participants who identified themselves as smokers at the time the survey was administered ranged from 6% for Other nonaboriginals to 77% for Inuit participants, with Caucasians and Dene/Métis reporting 22% and 48% smokers, respectively. Inuit participants had a significantly higher GM maternal cadmium concentration (1.50 μg/L, $P<0.0001$) than the rest of the ethnic groups, which was associated with the higher rate of smoking among Inuit participants and the high cadmium content of Canadian tobacco (Watanabe et al., 1987).

More participants from the Kitikmeot Region reported starting smoking cigarettes before they were 16 years old (79%) relative to Inuit from the Inuvik (52%) and Kivalliq (52%) Regions. Nearly 45% of the Inuit participants from the Inuvik and Kivalliq Regions who smoked reported starting between the ages of 16 and 20 years. Information about age at the commencement of tobacco use was not collected in the Baffin Region's survey, however, the Baffin's survey included a question about second-hand smoke, which indicated that 77% of participants from this region lived in homes where other people smoked.

The Government of the Northwest Territories (GNWT) has declared smoking an acute public health concern for most communities in the NWT, noting that 52% of all young women between 15 and 17 years of age living in the NWT are current smokers and that 43% of women of reproductive age smoke (GNWT, 2001). The GNWT has recommended that early tobacco cessation programs be focused on youth under 18 and that smoking prevention programs begin when children are from 6 to 8 years old. At the time of writing, there were tobacco prevention and cessation programs underway in both the NWT and Nunavut as part of Health Canada's multiyear Federal Tobacco Control Strategy. In Nunavik, 90% ($n = 175$) of Inuit women participating in a longitudinal contaminants health effects study smoked during pregnancy (Muckle et al., 2001a, b). This is in contrast to the 24% ($n = 1103$) of women who smoked during pregnancy in a Southern Quebec study (Rhainds et al., 1999). In addition to cadmium exposure, the long list of deleterious health effects related to tobacco use, including increased risk of cardiovascular disease and cancer and increased rates of childhood asthma from second-hand smoke, continue to warrant active and ongoing public health tobacco interventions in Canada's North.

In the present study, the mean levels of blood cadmium increased according to the amount smoked; there was a significant dose–response increase in cadmium levels relative to nonsmokers for both the moderate and heavy categories. These differences did not change when traditional food consumption was included in the analysis, indicating that tobacco smoke was the prime factor contributing to blood cadmium levels. This finding is consistent with results reported in Québec (Benedetti et al., 1994) and in Southern Ontario (Cole and Kearney, 1997) (Table 11). In the present study, there was a 9-fold difference in mean cadmium levels between smokers and nonsmokers, with 12.5 fold and 7.4-fold differences between those who smoked >8 cigarettes/day and those who smoked between 1 and 8 cigarettes/day, respectively, relative to nonsmokers. Similar results were reported in Québec, where blood cadmium levels measured in 554 people found that cigarette smokers had 10–20 times higher levels than nonsmokers (Benedetti et al., 1994). In a Southern Ontario study, the contributions of game (deer and moose) organ consumption and tobacco smoke were investigated in relation to blood cadmium levels, and tobacco smoke was identified as the overwhelming determinant, leading to a recommendation to advise reducing tobacco use before reducing organ meat consumption (Cole and Kearney, 1997). Public health advice developed in response to elevated levels of cadmium in moose and caribou in James Bay, which included consideration of the cadmium contribution of tobacco smoke, had previously reached a similar conclusion in their recommendations to the Cree Board of Health and Social Services (Archibald and Kosatsky, 1991).

In the North, Cd exposure is a potential concern for diets that include an abundance of kidneys and liver from some caribou herds (Elkin and Bethke, 1995; Receveur et al., 1996; Van Oostdam et al., 2003). For Dene/Métis, the intake of liver and kidney is generally low (Berti et al., 1998; Kim et al., 1998). While the consumption of marine and terrestrial mammal kidney and liver by Inuit may contribute to their Cd exposure, the high rate of smoking is a more important source, particularly given that the absorption of inhaled cadmium ranges from 10% to 60%, whereas cadmium absorbed from food ranges from 3% to 7% (Elinder, 1992). As in other regions, it has been recommended that in regards to cadmium, exposure reduction should be focused on reducing cigarette use rather than altering diet (Van Oostdam et al., 2003).

Differences in mean circumpolar blood Cd levels between ethnic groups reflect differences in smoking habits between these groups (Table 11). The mean values for Canadian Inuit from four regions (1.0–1.9 μg/L) were slightly higher than the mean for Inuit from Greenland (0.9–0.96 μg/L) (AMAP, 2003). Canadian Caucasian (0.43 μg/L), Other nonaboriginal (0.36 μg/L), and Dene/Métis (0.65 μg/L) participants had means comparable with the Russian centers of Norilsk (0.29 μg/L), Taymir (0.33 μg/L), Salekjard (0.40 μg/L), Dudinka (0.38 μg/L), and Yamal (0.20 μg/L). Maternal cadmium blood levels were low in Alaska and similar to those of nonindigenous population groups. The mean cadmium level reported for smokers in this study (2.2 μg/) was 2- to 2.4-fold lower than the mean levels reported for smokers in Ontario and Quebec (4.5 and 5.3 μg/L, respectively), perhaps indicating a tendency of pregnant smokers to smoke less than other smokers.

Table 11
Comparative cadmium concentrations (μg/L)

Location	Geometric mean (μg/L)	Sample type	Year collected	*N*	Reference	Comments
Canada						
Caucasian	0.43	Maternal	1994–1999	134	This study	22% smokers
Dene/Métis	0.65	Maternal	1994–1999	92	This study	48% smokers
Other	0.36	Maternal	1994–1995	13	This study	6% smokers
Inuit (all)	1.50	Maternal	1994–1999	146	This study	77% smokers
Baffin Inuit	1.65	Maternal	1994–1999	31	This study	82% smokers
Inuvik Inuit (Inuvialuit)	1.00	Maternal	1994–1999	31	This study	68% smokers
Kivalliq Inuit	1.43	Maternal	1994–1999	17	This study	82% smokers
Kitikmeot Inuit	1.86	Maternal	1994–1999	63	This study	77% smokers
NWT & Nunavut	2.24	Maternal smokers	1994–1999	192	This study	
	0.25	Maternal nonsmokers	1994–1999	191	This study	
Nunavik	0.27	Inuit nonsmokers	1988	7	Benedetti et al. (1994)	
Nunavik	5.3	Inuit smokers	1988	117	Benedetti et al. (1994)	
Quebec City	0.37	Urban nonsmokers	1988	45	Benedetti et al. (1994)	Caucasian
	5.2	Urban smokers	1988	161	Benedetti et al. (1994)	Caucasian
Ontario	4.53	Female smokers	1992–1993	65	Cole and Kearney (1997)	All current smokers
	0.17	Female nonsmokers	1992–1993	59	Cole and Kearney (1997)	
Greenland						
Disko Bay (D.B.)	0.9	Maternal	1994–1996	175	Bjerregaard and Hansen (2000)	Samples from 5 towns in D.B. area
Illullissat	1.2	Maternal	1999–00	29	Deutch, in AMAP (2003)	
Nuuk	0.68	Maternal	1999	34	Bjerregaard, in AMAP (2003)	
Ittoqqortoormiit	0.96	Maternal	1999–2000	8	Deutch, in AMAP (2003)	
Finland	0.13	Maternal	1996–1998	130	Soininen, in AMAP (2003)	
Russia (Siberia)						
Norilsk	0.29	Maternal	1995–1996	49	AMAP (2003)	Nonindigenous
Salekhard	0.40	Maternal	1996–1998	31	AMAP (2003)	Nonindigenous
Taymir	0.33	Maternal	1995–1996	18	AMAP (2003)	Indigenous
Yamal	0.20	Maternal	1996–1998	12	AMAP (2003)	Indigenous
USA (Alaska)						
Bethel	0.3	Maternal	2000	23	Berner, in AMAP (2003)	
Barrow	0.2	Maternal	2000	23	Berner, in AMAP (2003)	

4.3. Lead

Sources of exposure to lead include air, water, cigarettes, and food. Studies have indicated that environmental and blood lead levels have been decreasing in the Arctic since the ban of leaded gasoline and other reductions in lead pollution. Hansen observed a 7% decrease in blood lead levels among Greenlandic women from 1983 to 1988 (Hansen et al., 1990). Lead crosses the placental barrier and is generally present in slightly lower levels in the umbilical cord blood relative to maternal levels. The neurotoxic properties of lead, particularly to children younger than 6 years of age, and are well documented (e.g., Rice, 1998).

Mean maternal blood lead levels were significantly higher in Dene/Métis and Inuit participants than in Caucasians ($P<0.0001$). Cord blood lead levels ranged from 67% of the maternal level in Other nonaboriginal participants to 82% in Inuit participants, with Dene/Métis and Caucasians at 72%. Comparative blood lead levels are summarized in Table 12. The mean blood lead concentration reported for 283 adult Inuit women samples from Nunavik (Northern Quebec) in 1992 was 86 μg/L (Dewailly et al., 1994), or about 2.5-fold higher than the mean concentration in Inuit participants from Nunavut and the NWT in 1994–1999 (32 μg/L). Among Inuit participants in this study, there were significantly higher mean maternal Pb levels in the Baffin and

Table 12
Comparative lead concentrations (μg/L)

Location	Geometric mean (μg/L)	Sample type	Year collected	N	Reference	Comments
Canada						
Caucasian	20.6	Maternal	1994–1999	134	This study	(Cord blood, 15.2 μg/L; $n = 134$)
Dene/Métis	30.9	Maternal	1994–1999	92	This study	(Cord blood, 21.80 μg/L; $n = 86$)
Other	21.9	Maternal	1994–1999	13	This study	(Cord blood, 14.43 μg/L; $n = 13$)
Inuit	31.6	Maternal	1994–1999	146	This study	(Cord blood, 27.3 μg/L; $n = 169$)
Baffin Inuit	41.7	Maternal	1994–1999	31	This study	(Cord blood, 35.7 μg/L; $n = 61$)
Inuvik Inuit (Inuvialuit)	18.8	Maternal	1994–1999	31	This study	(Cord blood, 15.0 μg/L; $n = 30$)
Kivalliq Inuit	28.6	Maternal	1994–1999	17	This study	(Cord blood, 24.4 μg/L; $n = 16$)
Kitikmeot Inuit	36.1	Maternal	1994–1999	63	This study	(Cord blood, 28.9 μg/L; $n = 58$)
Nunavik	86	Blood	1992	492	Dewailly et al. (1994a)	Inuit adult
Nunavik	52	Cord	1994	59	Dewailly et al. (1994a)	Inuit newborn
Southern Quebec	15.8	Cord	1993–1995	1109	Rhainds et al. (1999)	Includes urban, rural, coastal, and suburban residents
Cornwall, Ontario	24	Females	1992–1993	32	Kearney et al. (1995)	Fish eaters
Cornwall, Ontario	19	Females		10		Non-fish eaters
Greenland						
Disko Bay	35.7	Maternal	1994–1996	175	Bjerregaard and Hansen (2000)	Cord blood, 29.2 μg/L; from 5 towns in Disko Bay area
Illullissat	50	Maternal	1999–2000	29	Deutch, in AMAP (2003)	
Nuuk	37	Maternal	1999	34	Bjerregaard, in AMAP (2003)	
Ittoqqortoormiit	31	Maternal	1999–2000	8	Deutch, in AMAP (2003)	
Finland						
	11	Maternal	1996–1998	130	Soininen et al. (2000), in AMAP (2003)	
Russia (Siberia)						
Norilsk	32	Maternal	1995–1996	49	AMAP (2003)	Nonindigenous
Salekhard	24	Maternal	1996–1998	31	AMAP (2003)	Nonindigenous
Dudinka	21	Maternal	1995–1996	27	AMAP (2003)	Nonindigenous
Taymir	29	Maternal	1995–1996	18	AMAP (2003)	Indigenous
Yamal	24	Maternal	1996–1998	12	AMAP, 2003	Indigenous
USA (Alaska)						
Bethel	33	Maternal	2000	23	Berner, in AMAP (2003)	
Barrow	11	Maternal	2000	23	Berner, in AMAP (2003)	

Kitikmeot Regions compared to the Inuvik Region ($P<0.0001$). Mean Pb levels were from 1.9- to 4.2-fold lower in the Baffin and Inuvik Regions, respectively, relative to those reported in Nunavik. Mean maternal blood lead (20.6 μg/L) and umbilical cord blood lead (15.2 μg/L) values for Caucasian participants in this study were comparable with values reported from Southern Québec (15.8 μg/L cord) and Ontario (24 μg/L for adult fish eaters, 19 μg/L for non-fish eaters) and higher than those reported from Finland (Table 12). As well, mean levels for Inuit (all) and Dene/Métis participants are comparable with those reported for indigenous populations in Greenland, Russia, and Alaska (Table 12).

Among all participants, 1.8% exceeded 10 μg/dL (100 μg/L) Pb, including 3.2% of Inuit participants ($n = 5$) and 2.2% of Dene/Métis participants ($n = 2$). Interventions established for individual blood levels >10–14 μg/dL include identifying possible exposure sources and for Pb levels >15–19 μg/dL include identifying possible exposure sources as well as medical/public health counseling to reduce future exposure (FPCOEH, 1994). Interventions with participants followed these recommendations according to their exposure level, including identifying possible sources of exposure, consultation with either the regional physician or environmental health officer, and repeat blood tests. Also, in some health regions there were community education programs informing community members about lead shot and recommending the use of steel shot.

The prevalence of 3.2% of Inuit participants with blood levels exceeding 100 μg/L is considerably lower than that reported in Nunavik, where 26% of women in the 18–44-years-old group had blood levels that equaled or exceeded this guideline (Dewailly et al., 2001). The ingestion of lead shot or lead shot-contaminated flesh in harvested waterfowl and game has been confirmed as the primary source of lead exposure in Nunavik (Lévesque et al., 2003). In the present study, the most highly lead-exposed participant lived in the Kitikmeot Region, which was the only region in Nunavut that identified the consumption of eider duck among the top five food items on an annual basis in a comprehensive dietary study (Van Oostdam et al., 2003). In Greenland, fragments of lead shot in waterfowl and frequent consumption of these birds, particularly the breast meat of eider and murre, are proposed to be causally linked to blood lead concentrations (Bjerregaard et al., 2004).

In 1999, lead shot cartridges were banned in Canada for use in the hunting of migratory birds. Toward the end of 1999, there was a public health information campaign in Nunavik about the use of lead shot. This intervention consisted of two parts: the first targeted hunters through the Hunters and Trappers Associations, who were asked not to use lead shot cartridges for hunting waterfowl and provided with the rationale for the request, and the second targeted stores, the proprietors of which were asked not to sell lead shot cartridges. The combination of the ban on the use of lead shot cartridges and the public health interventions are credited with the significant reduction of lead in umbilical cord blood in Nunavik between 1994 and 2001, more specifically during the year 1999 (Dallaire et al., 2003). At the time of writing, additional monitoring was underway in parts of Nunavut and the NWT, which should reveal whether similar trends are evident in these regions.

4.4. Essential trace elements

Essential trace elements Cu, Se, and Zn and many other required nutrients are present in the animal-based traditional diets of cultural groups in the circumpolar north. In participants from the NWT and Nunavut, maternal values of Cu and Se on average were significantly higher than cord blood values ($P<0.0001$), whereas cord values of Zn, on average, were significantly higher than maternal values ($P<0.0001$). GM maternal plasma Zn (580 μg/L) reported for Disko, Greenland (AMAP, 2003) was comparable to the mean of 555 μg/L for all participants in the NWT and Nunavut. Similarly, mean maternal Cu (2097 μg/L) for all participants was comparable to that reported for Disko, Greenland (2070 μg/L) and within the range of means reported for five communities in Norway (2090–2140 μg/L) (AMAP, 2003). Mean maternal plasma Se for all participants in the NWT and Nunavut (120 μg/L) was within the range of that for five communities from Norway (67.3–124 μg/L) (AMAP, 2003). These essential trace elements can have various and important effects on metal toxicity (Peraza et al., 1998). Also, there is evidence of a negative effect of smoking on fetal zinc status (Kuhnert et al., 1988) and also the influence of Se, Cu, and Zn on placental Cd transport (Zhang et al., 2004).

4.5. Sources

While the main source of cadmium for participants was cigarettes, there is considerable evidence that the major source of mercury and to a lesser extent lead was several traditional food species for both Dene/Métis and Inuit participants (Kuhnlein and Chan, 2000; Van Oostdam et al., 2003). The traditional food consumption data collected as part of the lifestyle surveys in the Mackenzie, Kitikmeot, Kivalliq, and Baffin Regions of this program, however, were intended to provide general information to assist with the interpretation of individual results and to guide the development of recommendations for individual interventions, if necessary. These data were not intended to provide a basis for the attribution of specific individual or regional exposure levels based on relative consumption. The extent of a program needed to quantitatively evaluate traditional food consumption regionally and seasonally for the NWT and Nunavut was beyond the scope of regional and territorial capabilities. Subsequent extensive work by the Centre for Indigenous Peoples' Nutrition and Environment (CINE) at McGill University for Dene/Métis and Inuit food systems, however, documented the consumption of multiple traditional food species, as well as evaluated their nutritional and contaminant compositions in communities across the NWT and Nunavut for both women and men (Chan et al., 1995; Receveur et al., 1996; Berti et al., 1998; Kuhnlein and Chan, 2000). Traditional food species that were identified as most often consumed by Dene/Métis were caribou, moose, and freshwater fish (whitefish, coney, trout), and by Inuit in the Baffin, Kitikmeot, Kivalliq, and Inuvik Regions were caribou, char, seal, and, to a lesser extent, muskox, goose, narwhal and beluga muktuk and whitefish (Van Oostdam et al., 2003). While the regional lifestyle surveys in the present study did not include specific species of freshwater or marine fish, responses within the category of "fish" can be assumed to include those specified in the CINE work. The results of the comprehensive studies conducted by CINE indicate that overall the participants in this study consumed traditional foods that appeared to be in a pattern consistent with those of others living in the same region. As well, CINEs work identified many extremely important nutritional, cultural, and economic benefits associated with a diet that includes several species of traditional foods (Kuhnlein and Chan, 2000). The importance of these benefits cannot be overstated in any contaminants discourse.

5. Conclusion

Levels of mercury, cadmium, and lead, copper, zinc and selenium have been quantified in a nonrandom subset of women of reproductive age who voluntarily participated in an exposure assessment between 1994 and 1999. These data, as well as organochlorine data previously reported for the same participants (Butler Walker et al., 2003), constitute results from the first human tissue monitoring program covering the entire NWT and Nunavut for multiple contaminants in populations at risk and establish a baseline upon which future comparisons can be made.

Three percent of Inuit women participants' MeHg exposure was in Health Canada's range of level of concern (20–99 μg/L), and 56% of Inuit cord samples exceeded the revised US EPAs MeHg BMDL of 5.8 μg/L. Ongoing monitoring of the populations at risk and traditional food species, as well as continued international efforts to reduce anthropogenic sources of Hg, are recommended.

Maternal cadmium levels were overwhelmingly driven by tobacco use, with smokers having significantly higher exposure relative to nonsmokers. Given the high prevalence of smokers among Inuit and Dene/Métis participants, a long-term commitment of resources by federal, territorial, and indigenous governments is recommended for active and ongoing tobacco prevention, reduction, and cessation interventions, particularly those targeted toward children, youth, and women of reproductive age.

While various traditional foods have been shown to contain elevated levels of metal and organochlorine contaminants, and the presence of contaminants has now been confirmed in Northerners across the Canadian Arctic, the harvesting and consumption of traditional foods is highly valued, and traditional foods are nutritionally, economically, and culturally superior to store-bought foods in nearly all cases. This presents a considerable challenge in both interpreting and communicating the well-known benefits and the less clearly understood risks of exposure to mixtures of these contaminants. Ongoing vigilance for monitoring populations at risk as well as key traditional foods species, particularly in light of the largely unknown potential influences of global climate change, is recommended.

Acknowledgments

We thank all those who have contributed to the successful completion of this work, especially the participants, regional Health and Social Services Board staff, community health workers, laboratory and maternity staff, and each of the regional Contaminants Consultation Working Groups. We thank regional coordinators Siobhan Moss and her colleague Sophie McRae, as well as Sharon Schultz and Marianne Demmer, whose work provided data essential to the exposure baseline and who declined coauthorship. Without the dedication and commitment of the following regional health agencies, this work could not have been undertaken: the (former) Mackenzie Regional Health Service, the (former) Kitikmeot Health and Social Services Board, the (former) Baffin Regional Health and Social Services Board, the (former) Keewatin (Kivalliq) Regional Health and Social Services Board, and the Inuvik Regional Health and Social Services Board. We also thank the following Aboriginal organizations, who represented Inuit and Dene/Métis within the Northern Contaminants Program, for their guidance and support during all phases of the project: the Inuit Tapiriit Kanatami (formerly Inuit Tapirisat of Canada) and the Inuit Circumpolar Conference, the Dene Nation, and the (former) Métis Nation-NWT. Many thanks to Dr. Olivier Receveur, who provided assistance with the traditional food consumption estimates. Thanks also to Dr. Andy Gilman, Health Canada, and Dr. Éric Dewailly, Laval University, for assistance during various stages of this work. We thank Mr. Jack MacKinnon (GNWT Health and Social Services, Yellowknife) for his long-standing support and commitment to this project. Dr. H.M. (Laurie) Chan provided helpful comments on an earlier draft of the manuscript, and Samuel Smith produced Fig. 1.

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